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AeroMACS System Characterization and Demonstrations

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Abstract

This The Aeronautical Mobile Airport Communications System (AeroMACS) is being developed to provide a new broadband wireless communications capability for safety critical communications in the airport surface domain, providing connectivity to aircraft and other ground vehicles as well as connections between other critical airport fixed assets. AeroMACS development has progressed from requirements definition through technology definition, prototype deployment and testing, and now into national and international standards development. The first prototype AeroMACS system has been deployed at the Cleveland Hopkins International Airport (CLE) and the adjacent NASA Glenn Research Center (GRC). During the past 3 years, extensive technical testing has taken place to characterize the performance of the AeroMACS prototype and provide technical support for the standards development process. The testing has characterized AeroMACS link and network performance over a variety of conditions for both fixed and mobile data transmission and has included basic system performance testing and fixed and mobile applications testing. This paper provides a summary of the AeroMACS performance testing and the status of standardization activities that the testing supports.

1.0 Introduction

Wireless communications for airport surface safety critical aviation applications has been considered since the late 1990s. The German Aerospace Center (DLR) researched the application of multicarrier code division multiple access to enable an Advanced Airport Data Link (ADL) to fulfill the communications requirements of the Advanced Surface Movement Guidance and Control System (Ref. 1). ADL aimed to provide data communications between air traffic controllers, airport authorities, and airline companies and aircraft on the airport surface. The possible use of 5000 to 5150 MHz band for the ADL system was considered at that time.

In the early 2000s, the Federal Aviation Administration (FAA) in conjunction with MITRE-CAASD began developing the Airport Network and Location Equipment (ANLE) concept. In (Ref. 2), ANLE is described as a “high integrity, “safety rated” wireless local area network (LAN) for the airport area, combined with a connected grid of multilateration sensors. The former would provide the cockpit with access to appropriate information via a high-bandwidth internet-like connection. The latter would use those same transmissions to derive three-dimensional position of the terminal—position that could then be broadcast via the same data link to provide all users with situational awareness on the airport surface. Adding simple transmitters to other surface-movement vehicles would allow for the development of a high-fidelity complete picture of the airport surface environment.” ANLE was proposed for the under-utilized 5091 to 5150 MHz band, which was allocated to the aeronautical radionavigation service (ARNS) for implementation of Microwave Landing System (MLS), but for which no MLS channels had yet been assigned. The 5091 to 5150 MHz band, also referred to as the MLS Extension Band, also contains an allocation to fixed-satellite service (FSS) for use by non-geostationary (non-GSO) mobile-satellite service (MSS) feeder uplinks. MITRE-CAASD performed initial analyses of the sharing of the MLS Extension Band between the MSS feeder links and the ANLE system as reported in Reference 3, to validate the feasibility of sharing this band between the two systems. This supported the addition of an aeronautical mobile (route) service (AM(R)S) allocation to the MLS Extension Band that could support the ANLE system at the World Radiocommunication Conference (WRC) 2007. Analysis of the compatibility between the airport surface wireless network and MSS feeder links has continued in order to establish the AeroMACS power transmission limits which will ensure, including work by both MITRE-CAASD and NASA Glenn Research Center (Refs. 4 and 5).

In 2002, the NASA Glenn Research Center considered possible communications, navigation and surveillance requirements for the airport surface in formulating a new research project eventually called Space-Based Technologies (SBT). At the Second Integrated Communications, Navigation and Surveillance (ICNS) Conference in April 2002, the recommendation was made to identify and address research efforts where current work is inadequate or underfunded regarding integration of multiple applications on the ground, the CNS performance requirements of integrated applications, and the data networking implications of this integration (Ref. 6). As a result, the SBT Project included a major effort in airport surface communications.

The SBT Project studied communications requirements on the airport surface and potential system architectures through in-house and contracted efforts. The results of these studies (Refs. 7 and 8) helped establish the basis for what became the AeroMACS system. Further studies by MITRE-CAASD (Ref. 9) built upon the SBT Project requirements studies and other analyses enabled the estimate of spectrum requirements supporting the MLS Extension Band AM(R)S spectrum allocation approved at WRC 2007.

By 2007, the FAA and Eurocontrol had completed a joint study called the Future Communications Study, investigating the future communications requirements for aviation. Among many outputs, this study concluded that the IEEE 802.16e standard was the preferred technology for an airport surface wireless communications network, thereby establishing an international consensus that enabled AeroMACS standardization to proceed.

Under the SBT Project, NASA Glenn Research Center entered into a cooperative agreement with Sensis Corporation which resulted in the establishment of what eventually came to be known as the NASA-CLE CNS testbed, located at the NASA Glenn Research Center (GRC) and adjacent Cleveland Hopkins international Airport (CLE). In this testbed, the feasibility of using wireless communications networks for integration of surface surveillance was established by interconnecting several Airport Surface Detection Equipment (ASDE-X) sensor units and transmitting sensor data to a central processing station (Ref. 10). Prior to the availability of IEEE 802.16e equipment, the surface wireless network was implemented using 802.11 equipment operating in the MLS Extension Band.

The SBT Project also developed a measurement campaign to characterize the MLS Extension Band propagation channel in the airport environment. Under a cooperative agreement with Ohio University, channel propagation measurements were made at several large, medium and small airports in the United States (Ref. 11). The test results enabled the development of path loss and airport channel models valid for the 5091 to 5150 MHz band that enabled the development of detailed simulations of 802.16e performance for the airport surface application.

In 2009, under a cooperative agreement with ITT-Exelis and with funding provided by the FAA, the first AeroMACS prototype was established within the NASA-CLE CNS Testbed. With the availability of 802.16e equipment, including base stations and subscriber units, tuned to the MLS Extension band now allocated for the AeroMACS service, testing was initiated to provide technical results upon which national and international standards for AeroMACS could be established. A description of the AeroMACS system development can be found in Reference 12.

During the past 3 years, extensive technical testing has taken place to characterize the performance of the AeroMACS prototype and provide technical support for the standards development process. This testing has characterized AeroMACS link and network performance over a variety of conditions for both fixed and mobile data transmission.

During 2012, the first two practical AeroMACS demonstrations have taken place, demonstrating both the fixed and mobile aspects of AeroMACS. The first demonstration utilized a Boeing corporation 737 jet equipped with an AeroMACS antenna and subscriber station, enabling the evaluation of the AeroMACS performance in bringing safety critical flight information to the cockpit. This event marked the first use of an aircraft involved in AeroMACS testing, augmenting previous mobile testing which utilized a ground vehicle offering speeds and reception characteristics which differ greatly from the commercial aircraft.

The second demonstration involved the suitability of AeroMACS to transmit live safety critical data between fixed assets. Live radar data from an Airport Surveillance Radar model 9 (ASR-9) was transmitted from the ASR-9 site to the air traffic control tower at CLE. This was the first demonstration of broadband transmission of live safety critical data over AeroMACS, and has established the potential for AeroMACS to be applied to many airport fixed asset communications requirements.

In the following sections, the AeroMACS prototype as instantiated in the NASA-CLE CNS Testbed is described, followed by a summary of AeroMACS performance testing. The focus of the paper will be on describing the most recent AeroMACS testing results, including the Boeing 737 aircraft mobility testing and the fixed safety critical data transmission testing. The status of AeroMACS standardization activities will also be provided.

2.0 AeroMACS Testbed Description

One of the primary goals of the NASA-CLE CNS Testbed as initially established was to enable testing of the interconnection of ASDE-X sensors via an airport surface wireless communications network (Ref. 13). The testbed included assets at three different airports, including CLE, Cleveland Burke Lakefront Airport, and Lorain County Regional Airport to allow testing of wide area multilateration, remotely staffed virtual air traffic control, assessment of 4D arrival and departure trajectories, and advanced integrated surveillance. The installation of an ASDE-X system for testing required the placement of eight multilateration sensors at CLE in order to achieve full airport surface coverage. The use of an initial IEEE 802.11 wireless network enabled the fixed ASDE-X sensors to be interconnected to the ASDE-X processor, allowing real-time airport surface surveillance to be established.

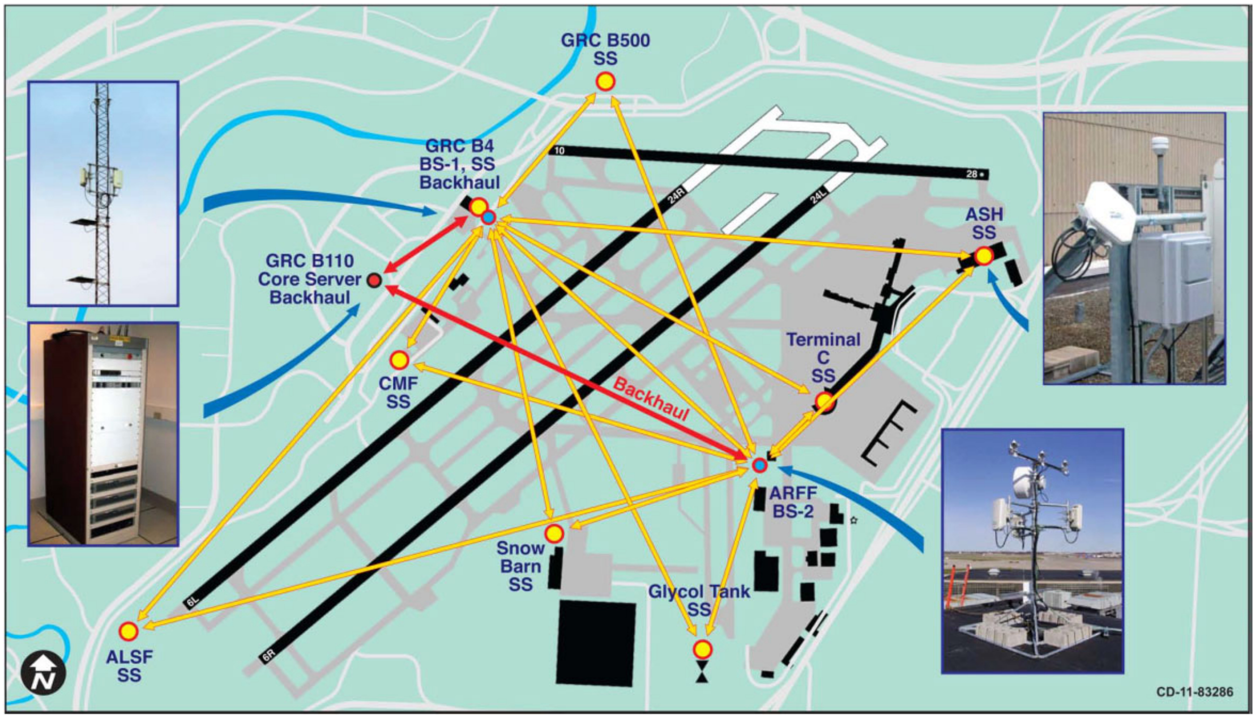

Figure 1.—AeroMACS prototype testbed.

Figure 1 shows a diagram of the current AeroMACS prototype testbed. Before the ASDE-X tests were completed, the prototype AeroMACS system was installed. This system consisted of two base stations and fixed and mobile subscriber stations. The fixed subscriber stations (denoted by “SS” in Fig. 1) were placed coincident with the ASDE-X sensors, allowing a final set of tests with the ASDE-X system using the AeroMACS prototype instead of the 802.11 network. These tests proved that AeroMACS provided equivalent performance in support of the ASDE-X system. After these tests the ASDE-X test system was removed, but the AeroMACS subscriber units remained at the same locations.

The location of the two base stations (BS-1 and BS-2 in Fig. 1) covers the majority of the airport surface of CLE. The base stations communicate with subscriber stations that are within their coverage. They also communicate with each other through a microwave backhaul link. This arrangement enables testing of handoffs between base stations that is required for mobile AeroMACS connectivity as well as for handling cases of temporary obstructions of fixed subscriber stations.

The AeroMACS testbed also includes a mobile element, called the Aeronautical Research Vehicle (ARV) as shown in Figure 2. The ARC consists of a ground vehicle fully equipped with a subscriber stations, test and measurement systems, and video camera. The ARV enables testing of many mobile aspects of AeroMACS without the cost and difficulty of using aircraft. However the ARV is limited in terms of size, speed and access compared to an actual aircraft, hence the testing described below was essential in demonstrating AeroMACS performance for real aeronautical mobile applications.

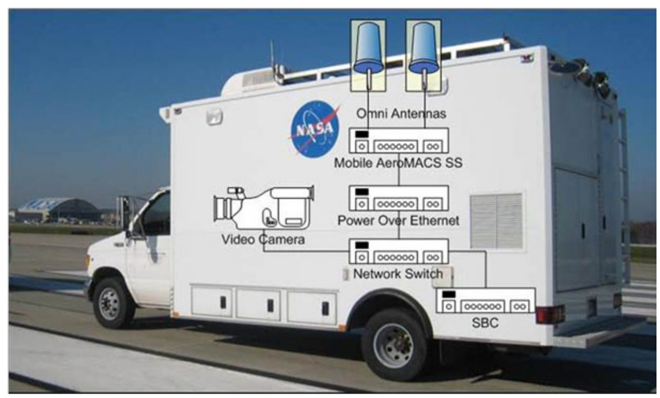

Figure 2.—Aeronautical Research Vehicle (ARV) for AeroMACS testing.

3.0 AeroMACS Prototype Testing

The primary AeroMACS prototype testing took place during 2010 and 2011 (Refs. 14 and 15). With the configuration described in the previous section, static testing of the AeroMACS network using the fixed subscriber stations has been ongoing since the establishment of AeroMACS equipment in 2009. However the mobility requirement for AeroMACS is the critical and most difficult one, hence the ARV was used extensively for these tests. The ARV often operated around the perimeter of CLE so as not to interfere with airport operations. Some critical testing also took place on the airport taxiways and runways when no aircraft operations were taking place. These various areas allowed both line-of-sight (LOS) and non-line-of-sight (NLOS) between the base stations and the mobile subscriber station.

The AeroMACS testing consisted of AeroMACS mobility testing; testing of Multiple antenna configurations (multiple-input/multiple output, or MIMO) on the vehicle; and testing of vehicle speed effects.

For all of this testing, the AeroMACS prototype network parameters are as described in Tables 1, 2, and 3.

Testing was performed for three mobile subscriber station antenna configurations: single antenna; two antennas separated by one wavelength; and two antennas separated by 10 wavelengths.

Base station transmit power was set to 25, 50 or 100 mW. The vehicle speed was set to 13, 26 or 40 kn.

In general the AeroMACS mobility testing showed robust performance, producing throughput rates ranging from approximately 0.5 to 4.5 Mbps, depending primarily on the distance of the vehicle from the base station as well as LOS/NLOS condition. This performance was seen in the several airport surface test regions: Runways (low multipath, high speed); Terminal areas (High multipath and LOS/NLOS)); and Service road (Long range, variable multipath, LOS/NLOS).

TABLE 1.—BASE STATION PARAMETERS

Transmit power	21 dBm maximum
Channel bandwidth	5 MHz
Maximum antenna gain	15 dBi
Antenna beamwidth	90° azimuth by 8° elevation
Antenna mode	2×2 MIMO (2Rx, 2Tx) Matrix A, MRC
Maximum transmission unit	1440 bytes
Downlink/Uplink ratio	60/40
Hybrid automatic repeat request (HARQ)	Enabled
AAA server	Enabled
PKMv2, EAP-TTLS security	Enabled
AES-128 air link encryption	Enabled

TABLE 2.—MOBILE SUBSCRIBER STATION PARAMETERS

Transmit power	Adaptable: 21 dBm maximum
Maximum antenna gain	8 dBi
Antenna beamwidth	Omindirectional on horizon
Antenna mode	2×2 MIMO (2Rx, 1Tx)

TABLE 3.—COMMON BASE STATION AND SUBSCRIBER STATION PARAMETERS

Modulation	Adaptive: QPSK, QAM-16, QAM-64
Forward error correction	Adaptive: CTC 1/2, 2/3, 3/4, 5/6

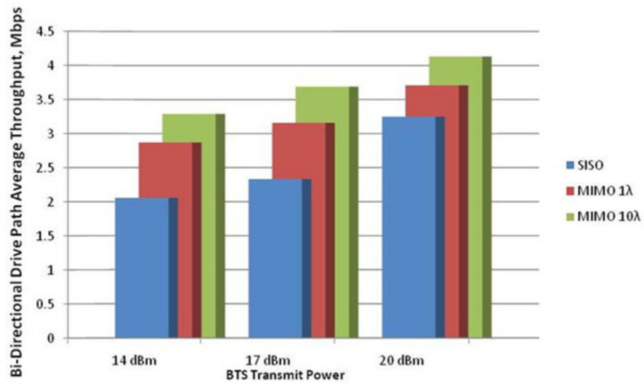

Figure 3.—Average throughput rate for the service road drive test.

The MIMO testing validated the use of use of MIMO for the subscriber station receive antenna as it showed improved receiver performance and lower base station transmit power requirements, enabling deployment of additional airport installations while still remaining below the mobile satellite service feeder link interference threshold.

Figure 3 shows the results of the service road test. The MIMO configuration outperformed the single antenna case, and the two antenna 10 wavelength spacing outperformed the one wavelength spacing. The one wavelength antenna spacing (2.3 in., 5.9 cm) performed the same as the single antenna case with reduced base station transmit power, verifying that the MIMO installation enables a reduction of base station transmit power and potentially more airport installations.

The measured data throughput as a function of vehicle velocity showed negligible difference up to 40 kt velocity. Additional velocity test results are presented in the next section.

4.0 Mobile Application Testing

The first mobile applications testing of AeroMACS was performed using a Boeing 737-700 that was provided by Boeing from their corporate fleet. These activities constituted the first use of AeroMACS using an actual aircraft, including use of an antenna designed for aircraft use (Refs. 14 and 16). The aircraft tests also differed from the ARV testing by offering significantly greater antenna height placement and vehicle velocities. The activities demonstrated the first two-way AeroMACS data link service providing flight critical data.

The aircraft was fitted with a Sensor Systems S65-5366-720 5 GHz antenna, temporarily replacing the standard VHF blade antenna as shown in Figure 4. The ARV's subscriber unit, a prototype AeroMACS unit with external antenna leads was installed in the aircraft and connected to the 5 GHz antenna. United Airlines provided hangar facilities for making the necessary onboard modifications.

Figure 4.—Boeing 737-700 aircraft used for AeroMACS mobility testing showing location of AeroMACS antenna.

The AeroMACS subscriber station onboard the Boeing 737-700 was configured to associate with base station sector 2-3 of the base station located at the ARFF facility on the eastern side of CLE (Fig. 1). The sector offers 60° of LOS coverage to the north and south of the sectors 270° heading.

Two activities were performed using this configuration. The first activity consisted of characterizing the performance of AeroMACS onboard a Boeing 737-700 by repeating a subset of the drive test scenarios previously conducted with the ARV for the AeroMACS baseline tests described in the previous section. Tests were performed using similar airport surface and runway routes at velocities up to 80 kt. The second activity further validated the performance of AeroMACS by demonstrating the successful use of safety critical aeronautical mobile applications using AeroMACS as the application data link. For both activities, the aircraft remained on the ground in taxi mode in the gate, terminal and taxi areas and on Runway 24 L (Fig. 1) as are appropriate for an aircraft using AeroMACS.

The Boeing 737-700 performance characterization resulted in the collection of AeroMACS performance data enabling a comparison with the baseline ARV test data. This comparison revealed that the Boeing 737-700 installed AeroMACS system had performance characteristics similar to the results obtained during the ARC testing. Of interest are the aircraft taxi tests as a function of velocity. A small throughput performance dependency with vehicle velocity was measured as aircraft speeds increased above 40 kt. Table 4 shows the average throughput as a function of velocity. Figure 5 shows the effects of vehicle velocity as the aircraft travelled down Runway 24 L. The effects of proximity to the base station are visible in this figure as well, with the base station location approximately one-third of the distance from the northeast end of Runway 24 L (Fig. 1). These test results indicate that AeroMACS can achieve good performance up to 50 kt as required by AeroMACS Profile (Section 6.0).

TABLE 4.—AVERAGE THROUGHPUT AS A FUNCTION OF VEHICLE SPEED

Speed, kt	Vehicle	Average throughput, Mbps
40	ARV	4.7
40	Boeing 737	4.8
60	Boeing 737	4.2
80	Boeing 737	3.9

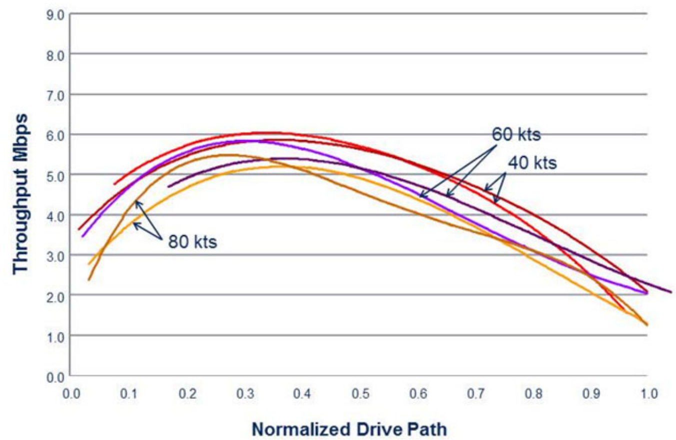

Figure 5.—Effects of vehicle velocity on throughput from runway 24 L taxi tests.

The AeroMACS validation activity required a suitable air traffic control or air traffic services application over AeroMACS to the Boeing 737-700 as it taxied across the airport surface. This effectively demonstrated the performance and feasibility of AeroMACS for safety critical mobility applications. The selection of an appropriate application was influenced by operational continuity considerations, including FAA plans to implement early data communications capabilities over VDL Mode 2 as part of the FAA's DataComm Program. Other considerations included the maturity of the data link service definition, the service availability (whether or not the service currently exists or can be suitably emulated), and hardware and software integration considerations.

The application chosen to validate the AeroMACS technology was a navAero T-1000 Electronic Flight Bag (EFB) system hosting a weather applications from WSI Corporation known as InFlight, capable of presenting cockpit staff with critical en-route meteorological data such as Airmen's Meteorological Information (AIRMETs), Significant Meteorological Information (SIGMETs), and terminal conditions through Meteorological Aerodrome Reports (METARS). Figure 6 illustrates WSI's EFB showing a regional radar graphic with textual METARs inset for CLE.

The Inflight system typically consists of a stand-alone SIRIUS satellite radio receiver which utilizes a 100BaseT Ethernet connection to interface the unit to an EFB or multifunction display (MFD). The system is normally meant

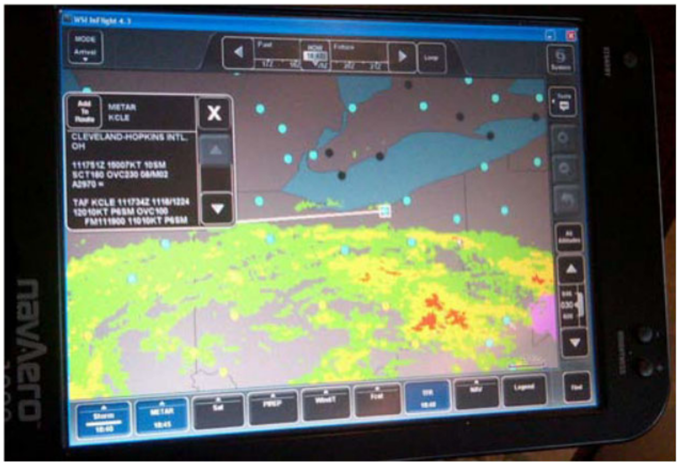

Figure 6.—A sample weather screen showing radar (with impending rain) and a current METAR for CLE.

to be used onboard an individual aircraft, however the intended demonstration consisted of interfacing the satellite receiver unit into the AeroMACS testbed and utilizing the wireless data link to provide “last mile” services to the cockpit. Due to a satellite receiver failure, the configuration was further altered to utilize AeroMACS to connect to WSI demonstration system connected to the internet.

WSI’s InFlight EFB weather application caches the packetized information broadcast over the Sirius satellite system. For timely information, the entire system, from receiver to EFB, should be on receiving broadcast updates. With SIRIUS data rates confined to 64 kbps and below, the 4 Mbps average throughput of the AeroMACS system’s wireless data link component to aircraft, or even the 1.44 Mbps interface to the Internet, had no negative impact upon the demonstration application.

5.0 Safety Critical Fixed Asset Testing

The opportunity to test AeroMACS using an actual critical fixed application was presented when Cleveland FAA initiated plans for the construction of a new Air Traffic Control Tower (ATCT) facility. The optimal location for construction of the new ATCT facility was determined to be in close proximity to the ASR-9 system. As a consequence of the new ATCT construction location, the existing radar sensor was scheduled for displacement to a location north of the airport. To enable seamless air traffic operations, the FAA operates an existing surveillance facility until a new radar system is built, optimized and thoroughly tested. The scheduled change of surveillance systems at Cleveland airport gave rise to the opportunity for testing AeroMACS utilizing the radar system scheduled for removal. With the approval and cooperation from FAA CLE Radar System Support Center (SSC), a plan was formulated to integrate AeroMACS into the communications infrastructure at Cleveland airport, interface it with the surveillance system and subsystems and conduct testing.

In preparation for testing in a relevant environment, communications equipment was obtained to conduct initial equipment setup and testing at a NASA GRC laboratory. Laboratory equipment configuration and layout was designed to replicate surveillance communications requirements at ASR-9 radar facilities. Laboratory equipment consisted of AeroMACS subscriber stations, Codex 3600 modems, Newbridge 3624 Channel bank systems and media converter equipment. The scope of the laboratory test was to configure modems and channel bank systems to transport information at the correct data rates while adhering to communication protocols in use. AeroMACS uses Transmission Control Protocol/Internet Protocol (TCP/IP) for communications exchange. The communications interface in use by telecommunications equipment commonly use T1 or DS-0 levels (1.544 Mbps). To enable the exchange of information between the T1 channel bank system interface and IP interface provided by AeroMACS, a media converter system was used. The media converter unit was able to packetize T1 channels and provide timing signals for end-to-end channel bank operation. In laboratory testing, the AeroMACS system was able to transport 24 channels of a T1 system. Error free end-to-end bit error rate tests were conducted and the laboratory system configuration was successfully tested under different data rate load configurations and with different modem parameters.

Starting in April of 2012, NASA and FAA personnel proceeded to install AeroMACS equipment at the ASR-9 surveillance facility and ATCT. The AeroMACS subscriber station was deployed at the radar tower structure and the Power Over Ethernet (POE) system and Newbridge Channel Bank were installed in the radar building. The POE and AeroMACS SS were connected using Ethernet cabling. At the ATCT, an AeroMACS subscriber station was installed on top of the Mezzanine building and cabled to the FAA equipment room where the Newbridge Channel Bank and POE where deployed. The wireless configuration utilized the base station to connect the subscriber station deployed at the ATCT and subscriber station deployed at ASR facility as shown in Figure 7. Although an actual National Airspace System deployment will not utilize a two-hop configuration, the NASA test bed AeroMACS prototype system did not offer a single hop architecture option. Bit error rate tests were conducted employing loading and configurations used in the earlier laboratory tests, showing zero bit errors generated during the data transmission.

The new surveillance system in Cleveland was commissioned in July 2012, thus freeing up the old radar system for AeroMACS testing. At the ASR-9 location, the AeroMACS subscriber station was interfaced to the ASR-9 Racal modem systems through the existing Data Probe switching system. At the ATCT the AeroMACS subscriber station was interfaced to the corresponding modem systems as shown in Figure 8. To monitor the performance of the communications system, a radar analysis tool (WRTADS) was used to display and record system performance. The analysis

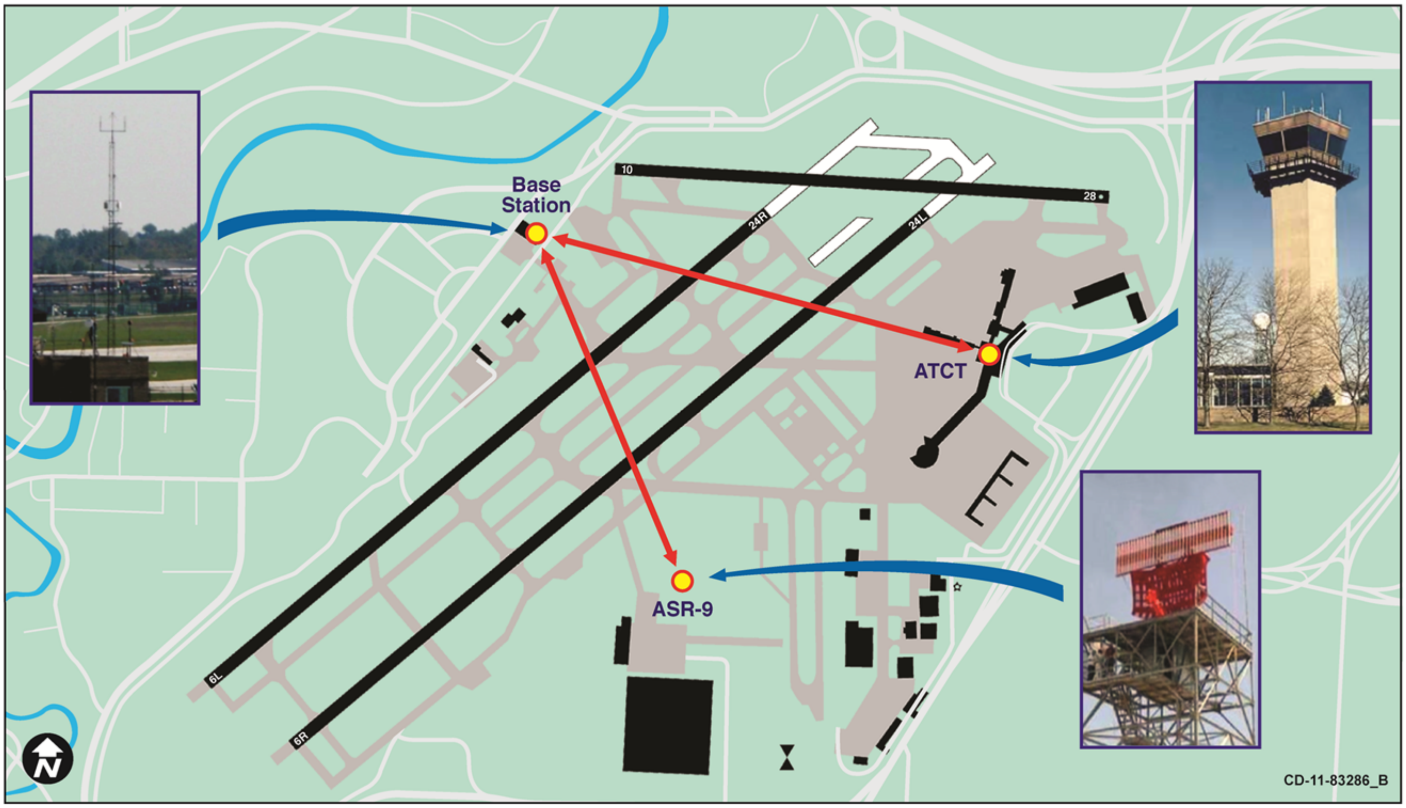

Figure 7.—Wireless configuration for ASR-9 safety critical fixed asset tests.

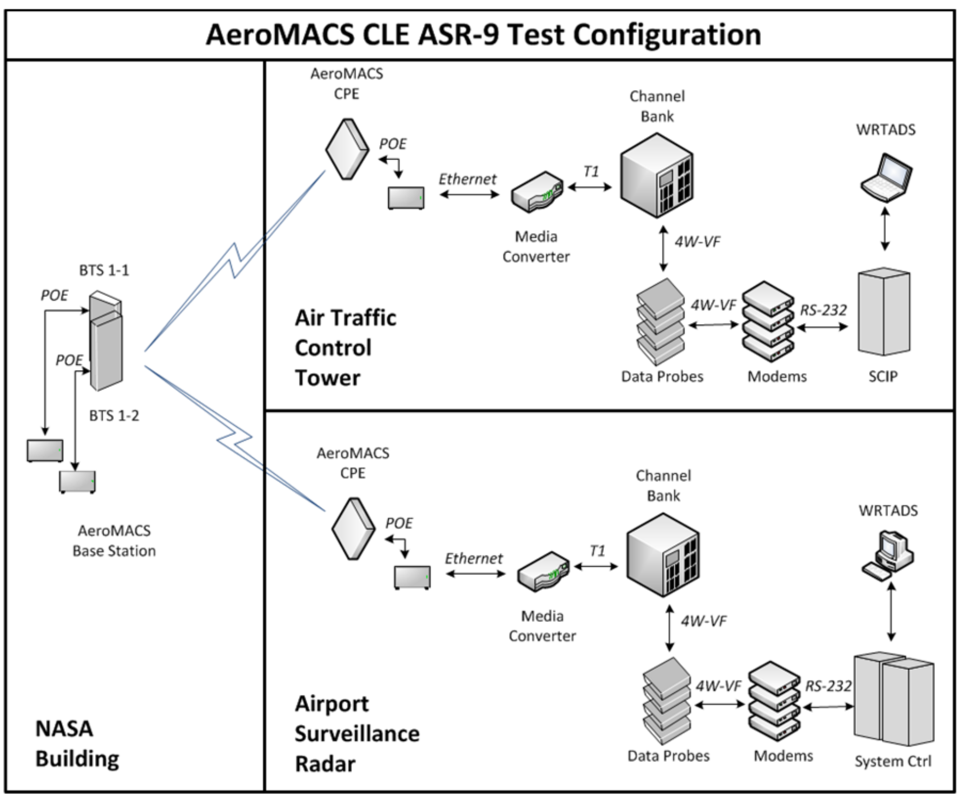

Figure 8.—AeroMACS-ATCT-ASR-9 interfaces.

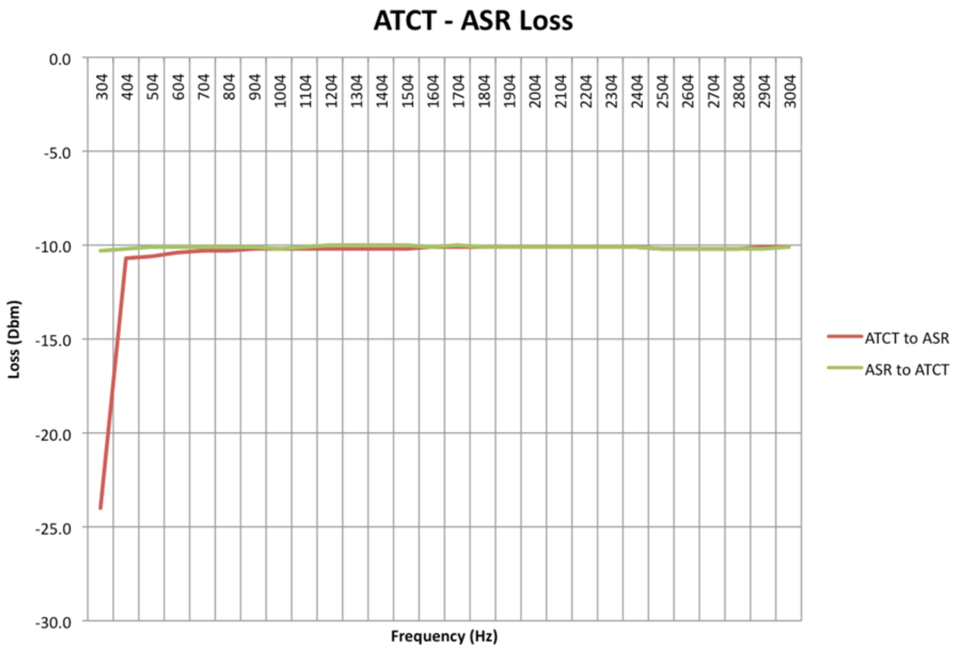

Figure 9.—AeroMACS-ASR-9 test voice grade line performance.

tool was deployed at both the ASR-9 and ATCT locations. At the ASR-9 location, the radar analysis tool was connected to the Communications Radar Interface Box where tracks produced by the radar system could be recorded for post processing. At the ATCT, the radar analysis tool was connected to the Serial Communications Interface Panel where received radar tracks were recorded for post processing and comparison with recordings at the sensor location. The testing indicated that the AeroMACS system was successfully able to transport critical radar information from the radar source to the ATCT. Figure 9 illustrates the performance of the voice grade line performance. The loss performance from 400 to 3000 Hz is negligible and illustrates the signal quality being provided to the modem system.

Future AeroMACS evaluations will include testing of system performance utilizing a single hop wireless configuration. This configuration would enable the evaluation of system latency under high communications demand loading using shared services configuration. The fixed asset testing successfully demonstrated that AeroMACS is able to meet the requirements for transporting critical surveillance data in a reliable and efficient way.

6.0 AeroMACS Standards Development

Worldwide interoperability is a critical element in the design of AeroMACS technology. AeroMACS will be required to provide seamless worldwide communications services while meeting the needs of many different users. Collaborative efforts to standardize AeroMACS are concurrently taking place in the United States and Europe. In the United States Radio Technical Commission for Aeronautics (RTCA) Special Committee (SC) 223 is working in the development of Minimum Operational Performance Standards (MOPS) and the WiMAX Forum has established a working group to address aviation interests. In Europe standardization efforts are being accomplished through EUROCAE Working Group (WG)-82 in developing MOPS and MASPS. The International Civil Aviation Organization (ICAO) is working in the development of Standards and Recommended Practices (SARPS) and Concept of Operations (ConOps). Common AeroMACS standards development in the U.S. and Europe has been requested by ICAO in response to the ANC-11 recommendation for global interoperability and to help expedite ICAO approval of international AeroMACS standards. The following sections provide information on ongoing standardization efforts by these organizations.

6.1 RTCA Standards Development

RTCA is an organization that through consensus develops Communications, Navigation, Surveillance (CNS) and Air Traffic Management (ATM) recommended standards for the United States Aviation. In 2009 a technology standardization effort for AeroMACS to support future mobile and fixed data communication applications and services for both ground/air and ground/ground communications services on the airport surface was proposed to RTCA’s Project Management Committee (PMC). On the seventh of August 2009, RTCA PMC approved the Terms of Reference (TOR) document to proceed with AeroMACS standards development. The TOR document specified the delivery of the following products: Aviation System Profiles for Airport Mobile Access Communications Network and MOPS for Airport Surface Wireless Mobile Access Communications Network.

6.2 RTCA SC-223

The RTCA Special Committee on Airport Surface Wireless Communications, SC-223, was established in August 2009 to develop the AeroMACS profile and MOPS. With support from industry, government, EUROCONTROL and WG-82 the U.S. final draft profile was completed at the end of 2010. The AeroMACS profile is a joint RTCA and EUROCAE development effort based on the WIMAX document, WiMAX Release 1 System Profile. This airport wireless communications technology has been developed based on a specific WiMAX Forum profile of the IEEE 802.16-2009 standard. Use of an established IEEE standard enables the aviation community to leverage extensive international standards collaboration and commercially provided components and services. The profile document specifies the use of selected 802.16-2009 technical parameters that best serve the aviation needs. Parameters have been selected to meet mobile station requirements considering different users, varied environments and operational uses. The AeroMACS profile closely follows the format of profiles developed by the WiMAX Forum for commercial and industrial use and is expected to be incorporated as one of several WiMAX Forum Certified profiles. Airborne MOPS development started in 2011 and is scheduled to conclude in late 2012. MOPS objectives are to develop standards for both Airborne Component and Ground Based base station components of AeroMACS.

6.3 WiMAX Forum

The WiMAX Forum is an industry-led, not-for-profit organization that certifies and promotes the compatibility and interoperability of broadband wireless products based upon IEEE Standard 802.16. The WiMAX Forum has created the Aviation Working Group. The Working Group acts as a focal point for Worldwide Aviation Industry interest in WIMAX as a technology for Aviation Applications, and promotes WiMAX as the premiere technology for Aviation Applications on a global basis. In August of 2010, an ad-hoc joint committee was formed between RTCA SC-223 and the WiMAX Forum to facilitate development of an AeroMACS profile.

6.4 EUROCAE Working Group 82 (WG-82)

The European Commission and EUROCONTROL have sponsored work projects under SESAR (Single European Sky ATM Research) Joint Undertaking (SJU) to progress the design and assessment of all future air/ground data link. EUROCAE assigned WG-82 to develop airport surface wireless communication standards in Europe. The group started in January 2010 with the purpose to develop the appropriate standards relative to new air-ground data link technologies including those associated with airport surface, and enroute/TMA using terrestrial and satellite communications (1). The working group is tasked with delivering a total of four documents. The AeroMACS Profile and Airborne equipment MOPS documents are jointly developed by RTCA and EUROCAE and the System level MASPS and Ground Equipment MOPS documents are developed only by EUROCAE. European WG-82 standardization support includes participation from EUROCONTROL, ANSPs (AENA, DSNA, DFS), Industry (INDRA, SELEXELSAG, THALES, SAAB, COBHAM, HITACHI) and Industry Forums (WMF). WG-82 is scheduled to deliver its document at the end of 2013.

6.5 ICAO SARPS

ICAO is a special agency of the United Nations responsible for the adoption of standards and recommended practices concerning air navigation. The development of Aviation Standards and Recommended Practices is done under the direction of the Air Navigation Commission (ANC) through the formal process of ICAO working group panels. The ANC is the ICAO technical body. In March of 2012 the first Aeronautical Communications Panel (ACP) Working Group S meeting convened in Montreal, Canada to commence standardization of airport Wireless Communications. The Terms of Reference document for Working Group S defines the following objectives for the group:

- Develop ICAO SARPs and Technical Manuals for AeroMACS.
- Define and describe AeroMACS security framework for worldwide interoperability.
- AeroMACS addressing and discovery mechanism that is consistent with ATN/IPS for global interoperability while permits local implementation flexibility.
- Coordination with international technical standardization bodies.
- Provide input to development of frequency planning criteria.

At the writing of this paper the development of SARP document outline is completed and work to define the standard is progressing with support from different states and industry. Additionally, a Concept of Use document is being developed to serve guide the development of requirements.

7.0 Summary

The need for an integrated wireless communications network capability for the airport surface has been recognized since the 1990s, and several research and study efforts have advanced the concept. Requirements analyses provided the airport surface communications spectrum requirements, and interference and spectrum sharing studies proved the feasibility of adding an AM(R)S allocation to the 5091 to 5150 MHz MLS Extension Band to accommodate the airport surface wireless communications system, which was accomplished at WRC 2007. The FAA-Eurocontrol Future Communications Study verified that the IEEE 802.16e standard is appropriate for the AeroMACS system. As this standard supports the well-known WIMAX implementation, an aviation profile based on WIMAX has been developed by RTCA and EUROCAE, and the name AeroMACS has been accepted to refer to the emerging airport wireless communications network. Channel propagation measurements have been performed at several airports, providing data for the development of channel models used for simulations of the AeroMACS profile. The availability in 2009 of IEEE 802.16e equipment tuned to the MLS Extension Band enabled the deployment of the first AeroMACS prototype as part of the NASA-CLE CNS Testbed located at the NASA Glenn Research Center and adjacent Cleveland Hopkins International Airport.

This paper has focused on the results of testing of the AeroMACS prototype from 2009 through 2012 at the NASA-CLE CNS Testbed, and has also provided the status of the AeroMACS standardization process. Testing of the mobile aspect of AeroMACS was performed first using a ground vehicle equipped with an AeroMACS mobile subscriber station. A second series of tests used a Boeing 737-700 equipped with an AeroMACS mobile subscriber station and a C-Band aircraft antenna to repeat some of the ground vehicle tests and also to demonstrate transmission of a real weather application representative of safety critical service application. A third set of tests demonstrated the transmission of high rate safety critical radar data over AeroMACS. From these results, it can be concluded that the performance of AeroMACS in supporting safety critical aviation communications for both fixed and mobile applications will be sufficient to enable the deployment of AeroMACS. The standards required to support future deployments and ensure international compatibility are advancing toward completion. Although AeroMACS testing and demonstration will continue while standards are finalized, AeroMACS is poised for operational deployment in the near future.

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